Robotic roles in transit

Uses of free flyers working with IVA Crew

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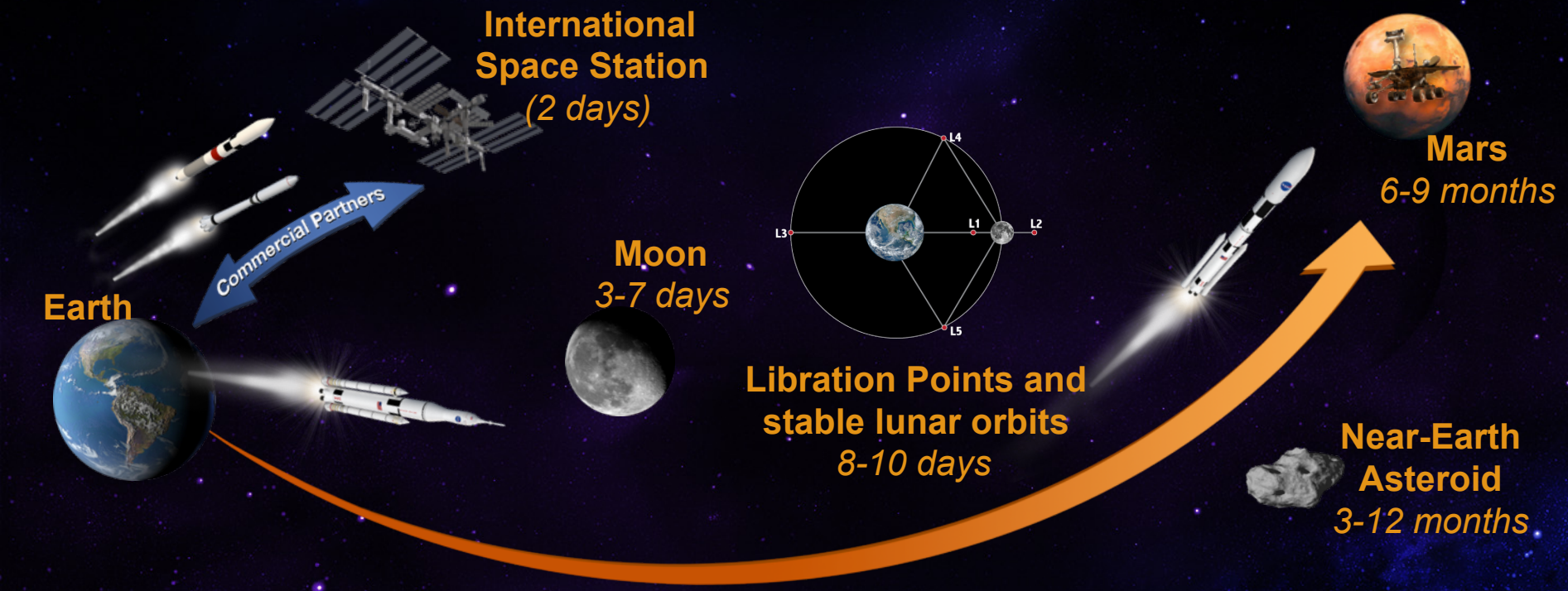
Exploration destinations

(one-way travel times)

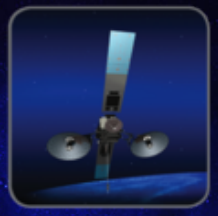


Future missions will be longer, more complex, & require new technology


Robotics and Mobility


Deep Space Habitation


Advanced Spacesuits


Advanced Space Comm


Advanced Propulsion


Resource Utilization


Human-Robot Systems

Why do we need robots in transit ?

Motivation

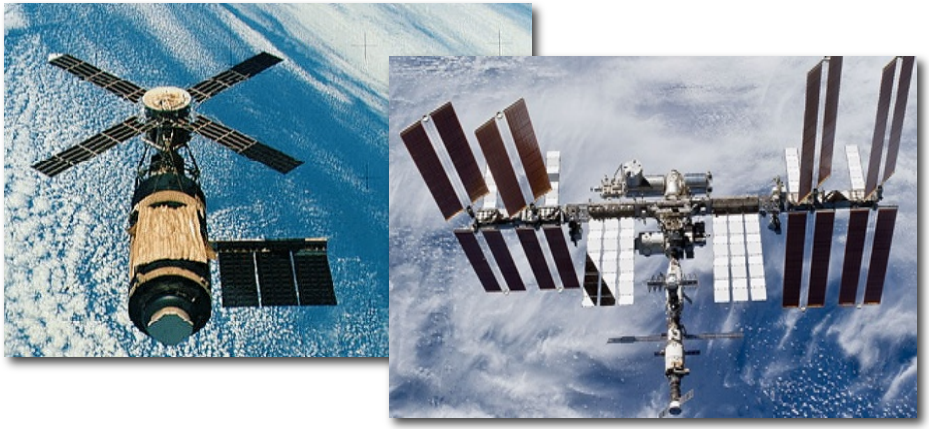
- Need to maintain human spacecraft
- Need to enhance crew productivity
- Need robots to do work before, in support of, and after humans

In-Flight Maintenance (IFM)

- Must perform IFM to keep spacecraft in a safe and habitable configuration
- Many IFM tasks are tedious, time-consuming, repetitive & routine
- Many IVA/EVA tasks cannot be done using only fixed sensors / actuators

Unmanned mission phases

- Setup spacecraft prior to human arrival (e.g., Mars exploration)
- Contingency situations (maintain vehicle when humans have to leave)



IN-FLIGHT MAINTENANCE TASKS

Inspect & monitor
- Provide mobile camera views
- Routine surveys and inventory
- Check payload status / health

Routine maintenance
- Change air/water filters
- Perform water draw/input on ECLSS
- Payload adjustment & trouble shooting

Contingency response
- Assess environment after fire event
- Assess & repair Leaks/MMOD damage
- Power cycle/reboot electrical equipment
- Actuate mechanisms (hatches, valves, etc.)

In-Flight Maintenance on the ISS

Extra-Vehicular Activity (EVA)

- Not enough crew time to do everything (only 1 EVA per year)
- Crew must always carry out “Big 12” contingency EVA’s
  - Maintain electrical power system
  - Maintain thermal control system
- Worksite prep & tear down requires 2-3 hr per EVA

Intra-Vehicular Activity (IVA)

- Crew spends **a lot** of IVA time on maintenance (40+ hr/month)
- Routine surveys require 12+ hr/month
  - Air quality, lighting, sound level, video safety, etc.
- Crew must always carry out contingency IVA surveys
  - Find and repair leaks, combustibles, etc.

Repetitive and Routine IVA Tasks on ISS

Camera positioning

- Many cameras are used for IVA work
- Crew has to manually reposition video cameras monitored by mission control
- Camera are essential for many tasks
  - Safety surveys
  - Equipment and payload inspections
  - Crew “over the shoulder” views during IVA activities

Logistics

- Crew must locate equipment and materials needed for IVA work
  - Crew spends **up to 1 hr per day** manually searching for items
  - **6,000+ “lost” items in ISS Inventory**
- Automated logistics is a key HEOMD priority for ISS and future missions

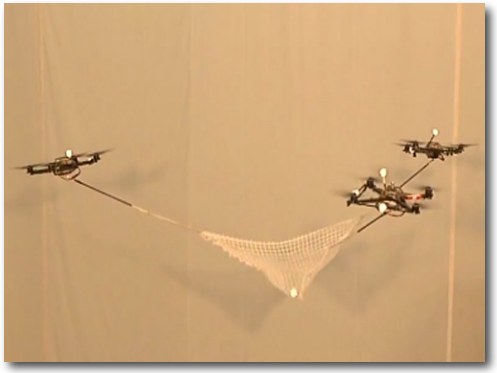
Assistive Free-Flyers

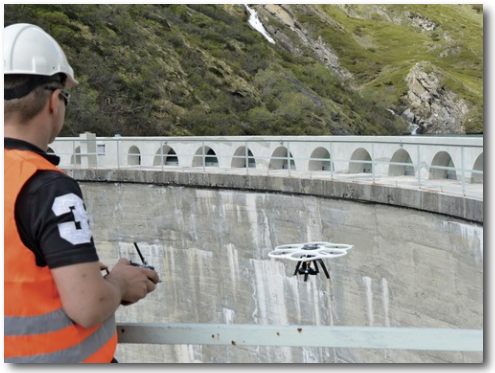
What are AFF's?

- Small free-flying robots that assist humans *(Szafir, Mutlu, & Fong 2013)*
- AFF's perform exploration, surveillance, inspection, mapping, transport, etc.
- AFF's are often co-located with human and operate in human environments

Key design issues

- Autonomy
- Ecological fit
- Human-robot interaction
- Morphology
- Navigation
- etc.





Assistive Free-Flyers

“Drones Wirelessly Automated to Retrieve Forensics” (D.W.A.R.F.)
Marvel’s Agents of S.H.I.E.L.D. (ABC Television)

Assistive Free-Flyers

Co-location

- Humans and robots working in shared space, close proximity
- Neither gets in the way, nor disturbs, the other

Interaction

- Indirect – mediated by handheld user interface (tablet)
- Direct signaling (blinkers, light projection)

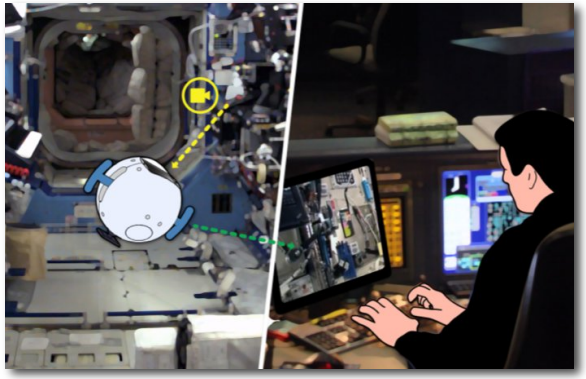
Social intelligence

- AFF's move "naturally": smooth motions, gradual acceleration, curve/arcing flight paths
- AFF's aware of human intent – yields "right of way"

AFFs for Human Exploration Missions

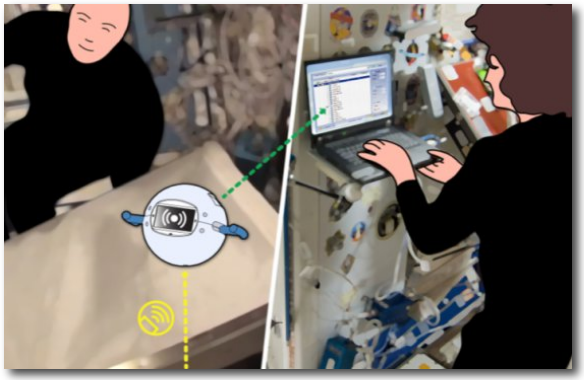
Support crew

- Prepare for crew activity
- Display or prompt crew procedures
- Transport tools / equipment
- Transport material



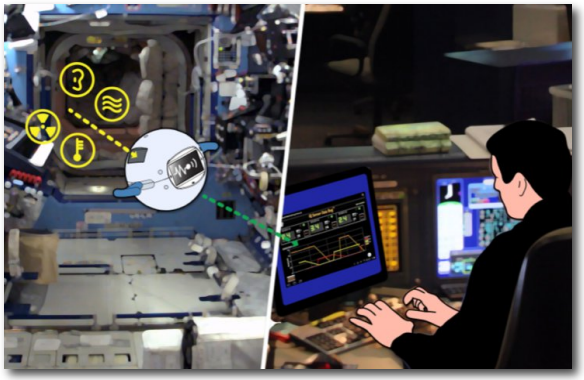
Support ground control

- Perform logistics (inventory, etc.)
- Remotely operated mobile sensor
- Embodied communication device
- Remote presence (mobile camera)



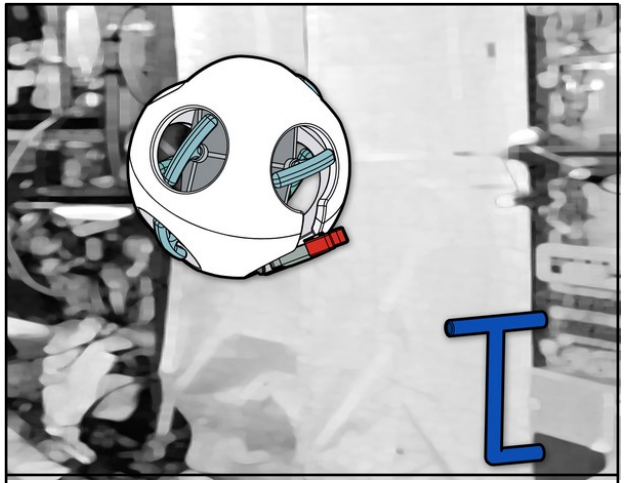
Support spacecraft

- In-flight maintenance
- Monitor IVA environment
- Identify contingency situations
- Perform initial emergency response

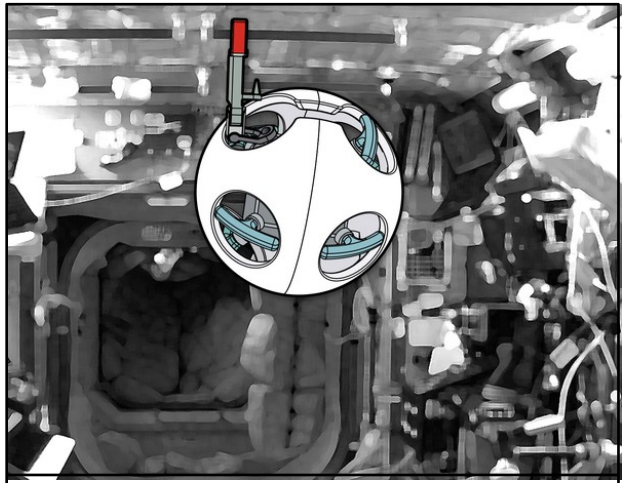


Use Case: Mobile Camera

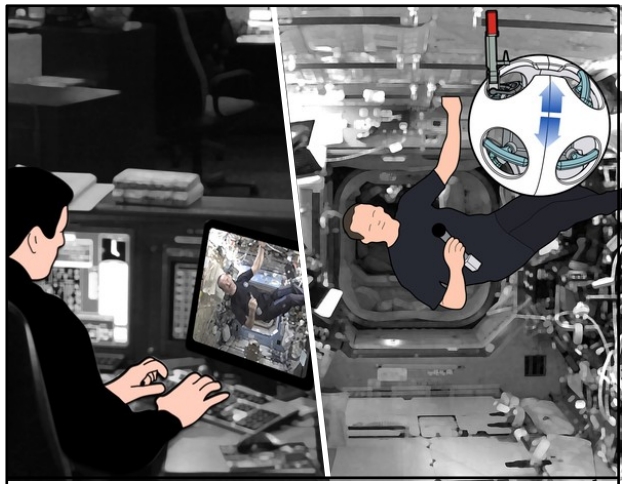
Before crew activity, ground controller starts free-flyer. Free flyer prepares for flight.



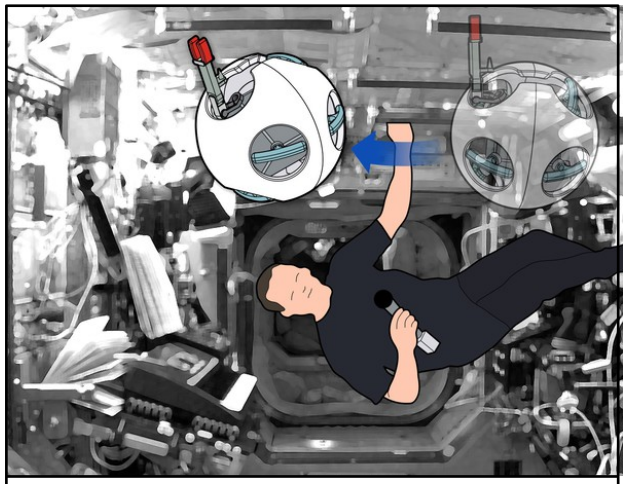
Free-flyer undocks and flies to module.



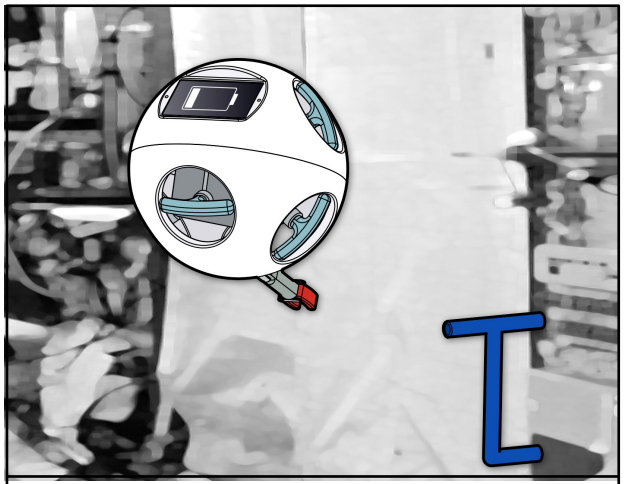
Free-flyer perches and waits for astronaut.



Ground controller controls camera position as astronaut moves around.



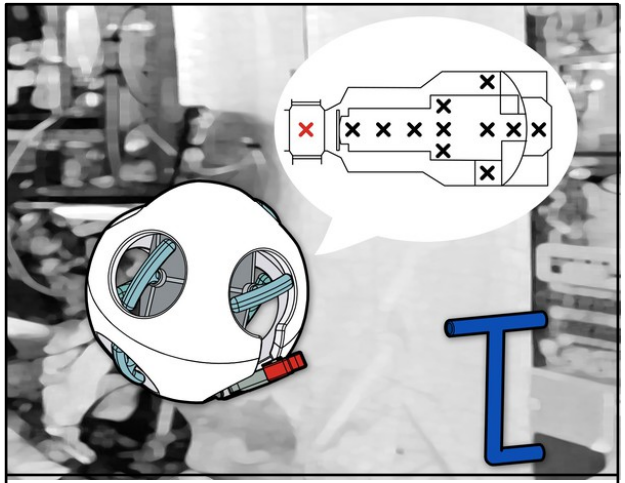
Free-flyer moves to new perch because astronaut is blocking the view.



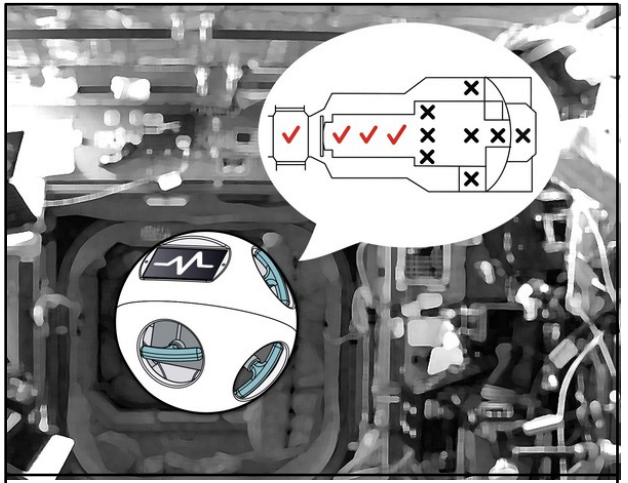
After activity, free-flyer returns to dock to recharge.

Use Case: Environment Survey

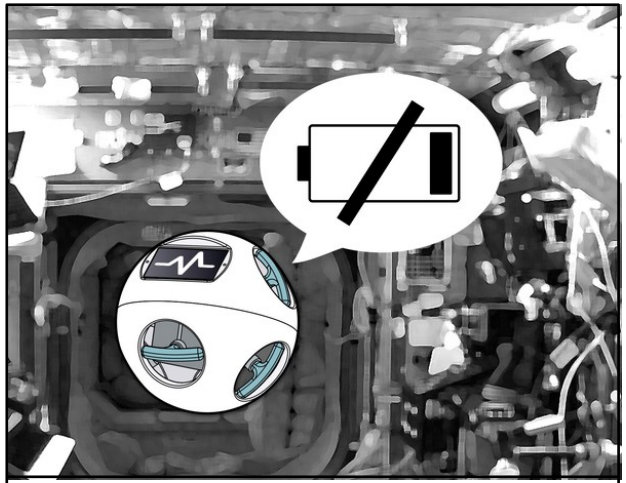
Ground controller activates the Free-flyer, uploads an sound level measurement file, and initiates SURVEY.



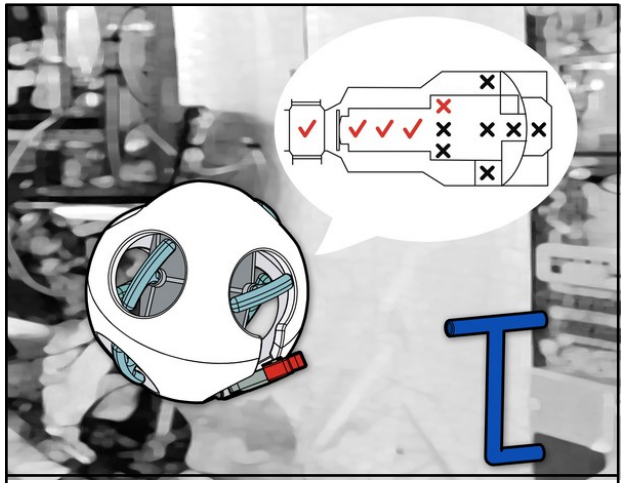
Free-flyer undocks and autonomously heads to first survey point.



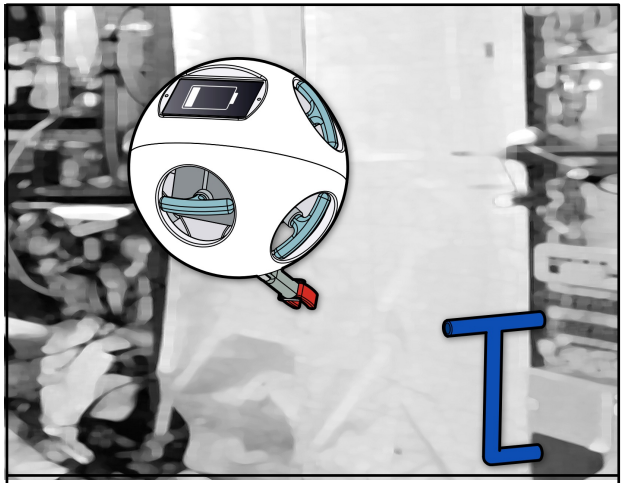
Free-flyer moves from point to point, taking measurements, and avoiding astronauts and equipment along the way.



Half way through the survey, battery requires recharge. Free-flyer returns to the dock.

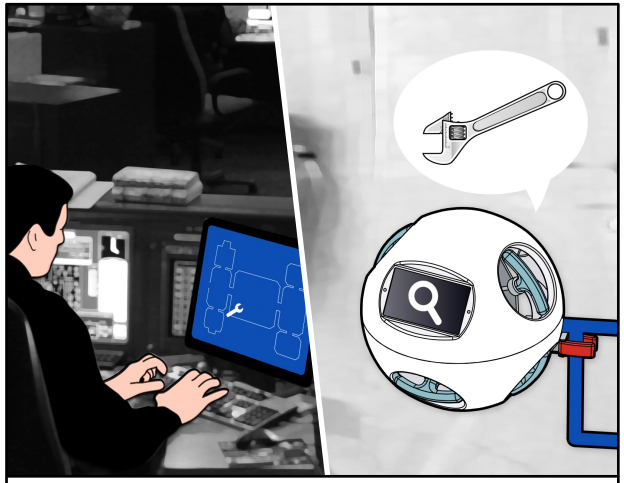


Once recharged, the Free-flyer continues performing the survey.

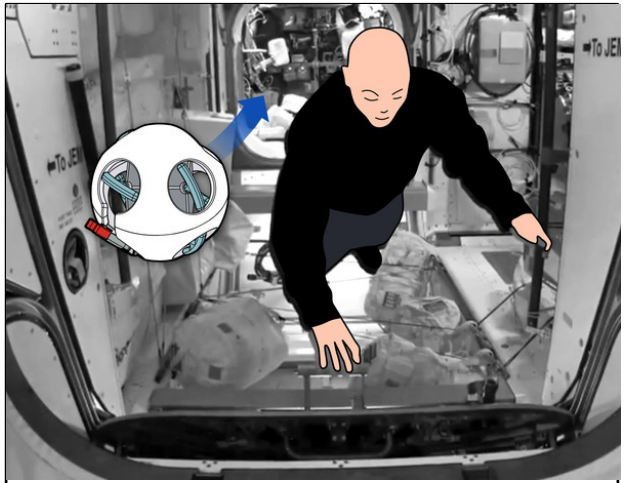


Free-flyer returns to dock.

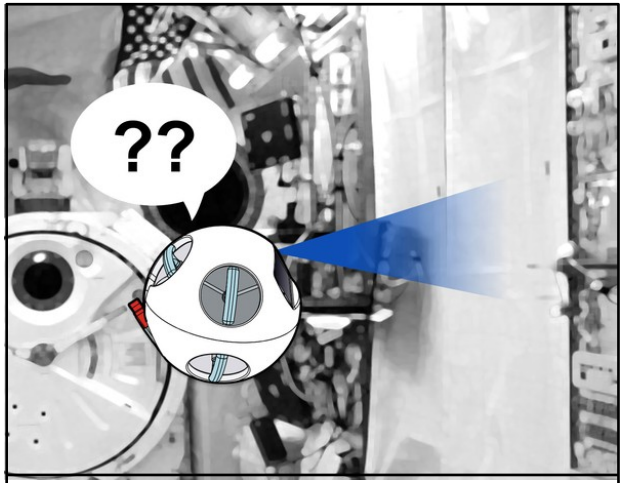
Use Case: Inventory and Search



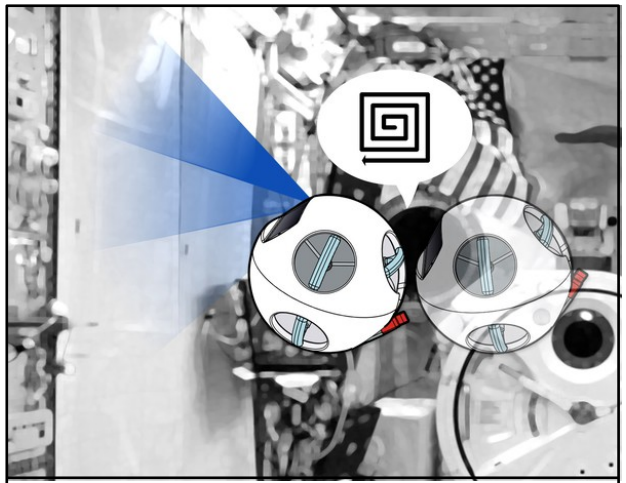
In advance of crew activity, ground controller activates the free flyer, uploads tool ID and expected location, and initiates SEARCH.



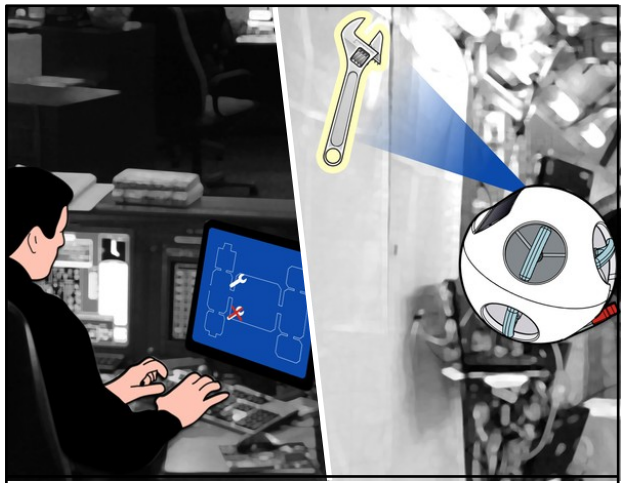
Free-flyer undocks and heads to expected location. Free-flyer avoids astronauts and equipment along the way.



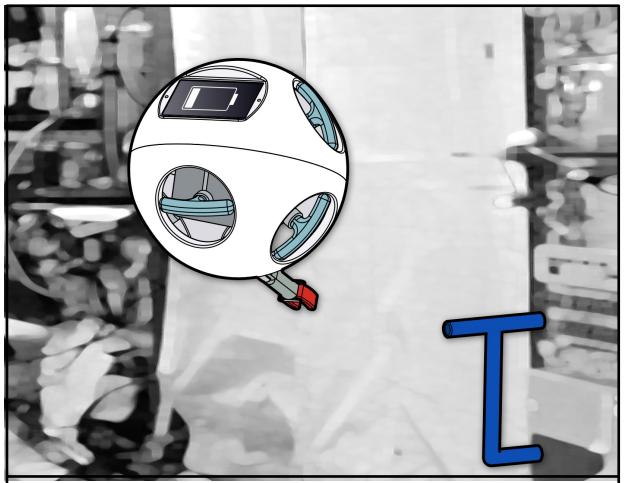
Free-flyer scans the expected location with its RFID reader, but the tool is not there.



Free-flyer initiates automated search pattern.



Free-flyer locates tool at the other side of the module and updates logistics database.



Free-flyer returns to dock.

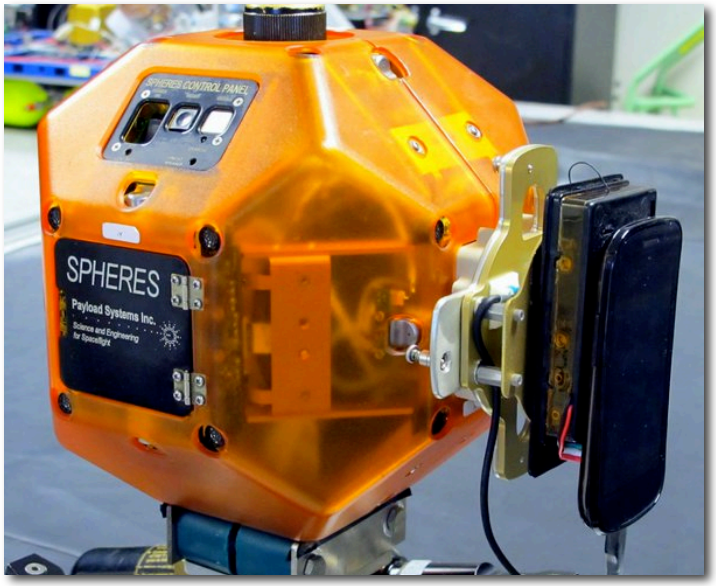
State-of-the-Art: Smart SPHERES

Mobility: SPHERES satellite

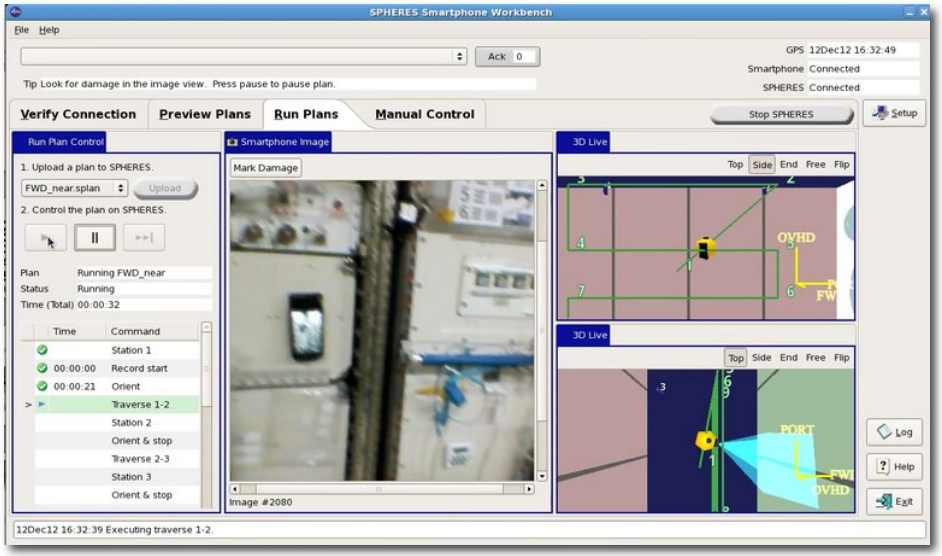
- IVA free-flyers (NASA / DARPA / MIT)
  - 22 cm diameter, 4 kg
  - Cold-gas propulsion + AA batteries
  - External sonar beacon localization
- 3 units installed on ISS (2006)
  - 52+ test sessions, 340+ hr crew time

Computing: Google Nexus-S

- Android smartphone
  - 1GHz Cortex A8 (ARM) + GPU, 512 MB RAM, 16 GB flash
  - 3-axis gyro, 3-axis accel., two color cameras
  - 802.11 b/g/n (Wi-Fi)
- Robotics software
  - RAPID middleware
  - Basic teleop + command sequencing
  - Ground control user interface

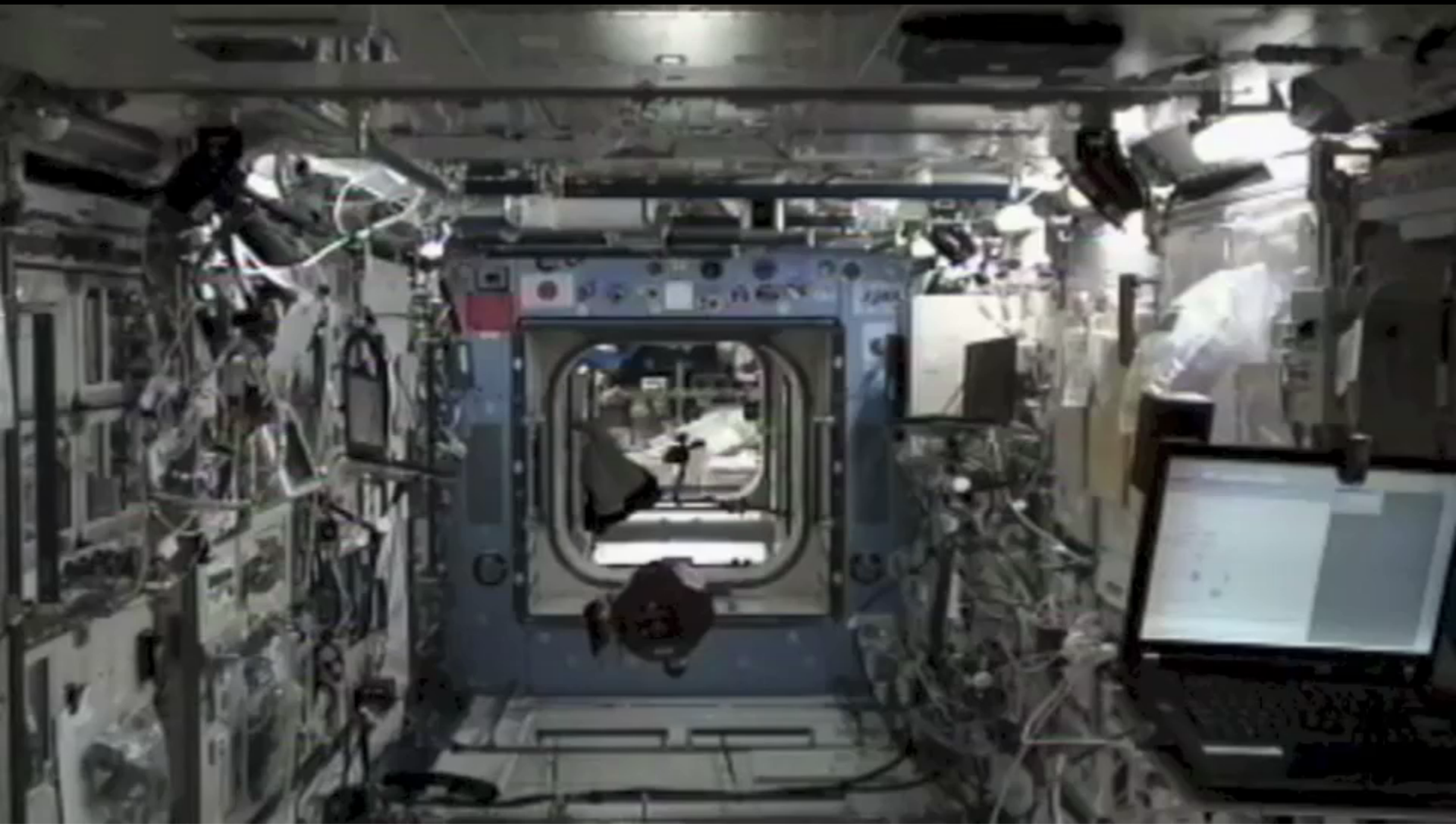


SPHERES with Google Nexus S smartphone



Ground Control User Interface

IVA Survey with Smart SPHERES



December 12, 2012 (ISS Japanese Experiment Module)
Crew: Kevin Ford, Expedition 33 Commander

Questions ?

Luca Parmitano working with Smart SPHERES in the ISS Japanese Experiment Module

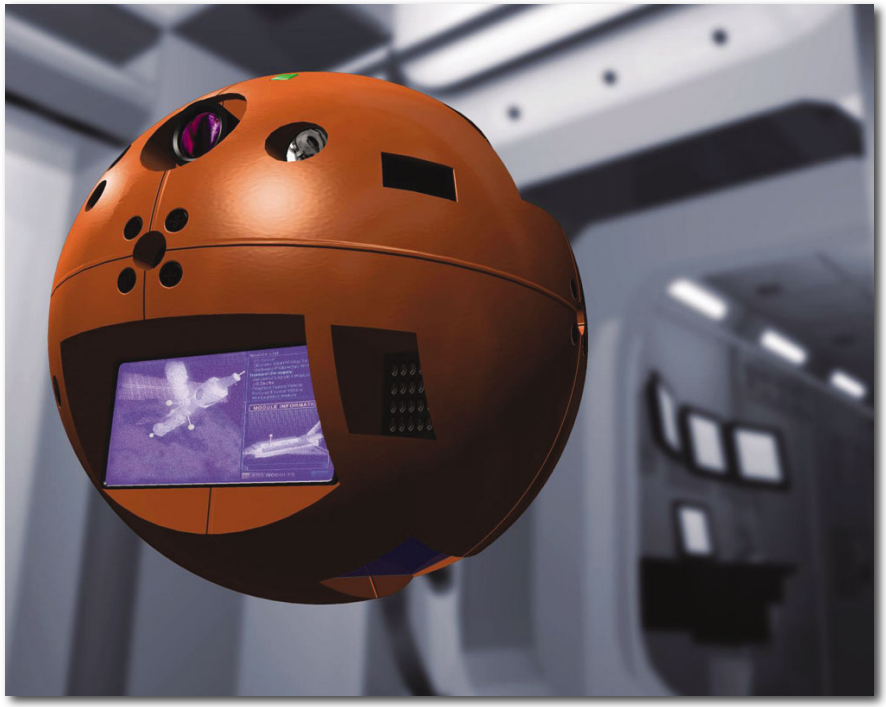
ISS Free-flyer Development (2014 - 2017)

Safeguarded movement

- 6-DOF navigation
  (computer vision & Wi-Fi localization)
- Static & dynamic obstacle detection
- Collision avoidance

Automated operations

- Automated task execution / notification
  (ground supervisory control)
- Automated health monitoring
  (self diagnostics / prognostics)
- Autonomous perching & station keeping
- Autonomous free-flyer docking / resupply



Telerobotic sensor platform

- 6-DOF localization (no beacons): Wi-Fi + structured light (Kinect) + stereo vision
- Environment sensors and monitoring algorithms (sound, light, radiation)
- RFID sensor for sparse area inventory
  (key component of automated logistics)

Open and extensible platform

- Expansion port (mechanical, data, & power) for new payloads
- High-level programming interface
  (protects safety critical functions)
- Support microgravity experiments and E/PO (robotic competitions)